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Airfield Maintenance & Repair: A Decision-Maker's Guide

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Airfield Maintenance & Repair

A Decision-Maker's Guide

University of Washington
CEE – 600 Independent Study
Spring 2003

Eric J. Hawn

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1. INTRODUCTION

Pavement is simple enough: groom some dirt, put down a layer or two of concrete or asphalt and open for traffic. The deceptive simplicity of airfield pavement is filled with a plethora of latent complexities – challenges airfield managers and engineers are expected to master. Truly effective pavement maintenance is an advanced skill, at the very least. Since many of the nation's military and commercial airfields have already been built, this aptitude for pavement upkeep is a growth industry that is increasing in demand. Furthermore, rapidly advancing technology in both aircraft and pavements, as well as shrinking fund allocation for airfield maintenance is adding to the complexity of the field. Increasing operational and environmental restrictions also contribute to the intricacy of effective pavement maintenance and repair by limiting available options to complete required upkeep.

Success of these maintenance actions is based on the construction materials and methods selected, along with the scheduling and phasing of the work. Since safety and quality control are equally as important as adherence to tight timelines, plans for pavement repair and maintenance must be finely detailed, coordinated well in advance, and closely tracked during execution. This report's target audience is airfield managers and engineers who possess a basic working knowledge of airfield operations and pavement structures. Since the airfield manager's responsibilities are vast and deep, this paper aims to lead engineers and managers toward a proactive approach in meeting the inevitable pavement maintenance and repair requirements. Four major areas of focus will accomplish this goal:

- Pavement Problems
- Analysis Methods
- Design and Installation Tools
- Project Planning Considerations

This approach will be delivered with a framework similar to one of the business world's problem-solving models: identify, assess, plan, implement, measure, and improve. Ultimately, a holistic strategy for maintaining airfield pavements will be introduced, including recommendations to sustain the highest performing pavements at the greatest value for applied resources.

2. AIRFIELD PAVEMENT DISTRESSES

In order to keep airfields running in an efficient, safe, and cost-effective manner, engineering teams must first possess, or contract for, the ability to accurately identify defects in their pavements. Clear definition of a problem is the first key step in developing any effective engineering solution. For this reason, airfield maintainers should familiarize themselves with the common forms of pavement failure. Table 2.1 and Table 2.2 synthesize some of the key ACP and PCCP distress modes, the associated causes, and some recommended remedies, as adapted from the Federal Aviation Administration and from Shahin.

Table 2.1 Common Asphalt Concrete Pavement Distresses

TYPE OF DISTRESS	DESCRIPTION	PROGRESSION/ CAUSE	REPAIR OPTIONS
Alligator Cracking	Series of interconnecting cracks that form sharp-angled pieces	Heavily loaded areas form cracks at the bottom of ACP layer and propagate to the surface, eventually interconnecting	Surface seal (minor), overlay, partial or full depth patch, reconstruct
Bleeding	Film of bituminous material on pavement surface that lowers skid resistance	Excessive amounts of asphalt binders in the ACP mix during placement, or low air void content; asphalt fills voids of mix during hot weather and expands onto surface (no return in cold weather).	Apply heat, roll sand, and sweep off loose material
Block cracking	Generally rectangular interconnecting cracks in large, non-traffic areas	Asphalt shrinkage and daily temperature cycling.	Crack seal and/or surface seal; heater scarify and overlay.
Corrugation	Closely spaced ridges and valleys perpendicular to traffic and spaced at intervals of <10 ft	"Washboard" or ripple effect caused by unstable pavement surface or base in traffic areas	Leave as is (minor) or reconstruct
Depressions	Pavement surfaces slightly lower than adjacent area	Settlement of supporting soils or areas inadvertently built up during construction; causes ponding of rain water which can increase hydroplaning potential	Leave as is (minor), partial-depth or full depth patches
Jet Blast Erosion	Asphalt binder gets burned or carbonized (blackened)	Accelerates surface deterioration and can eventually allow aggregate to break away from asphalt binder at pavement surface	Leave as is (minor); apply surface seal or partial-depth patch

Joint Reflection Cracking from PCC	Thermal and/or moisture conditions cause movement at joints between PCC slabs beneath asphalt surface, resulting in longitudinal and transverse cracks	ACP cracks from the bottom toward the surface. Cracks may widen and break further under loads (spalling and FOD potential).	Seal cracks 1/8" –1/2", partial depth patch, or reconstruct joint
Longitudinal and Transverse Cracking	Cracks that form parallel or perpendicular to runway centerline or paving direction	Poorly constructed lane joints, shrinkage of ACP due to low pavement temperature, or cracks in layers beneath ACP surface (not PCC joints)	Seal cracks 1/8" –1/2", partial depth patch, or reconstruct joint
Oil/Hydraulic Fluid Spillage	Breakdown or loss of strength of pavement surface from a petroleum product or other solvent spill	Infiltrates asphalt pavement surface and moves downward, causing aggregate and asphalt binder to lose bond	Partial or full depth patch

Table 2.2: Portland Cement Concrete Pavement Distresses

TYPE OF DISTRESS	DESCRIPTION	PROGRESSION/ CAUSE	REPAIR OPTIONS
Blowup	Upward movement of slab edges – buckling – in the vicinity of a pavement joint	Transverse crack does not allow expansion of the slab in hot weather.	Immediate partial or full-depth patch or slab replacement
Corner Break	Crack that measures less than half of the slab length on both sides, as measured from the same corner; crack extends full-depth along the surface of the slab	Warping and curling stresses from thermal forces, as well as imposed loads and loss of support beneath slab.	Seal cracks, full-depth patch, or slab replacement
Longitudinal, Transverse, and Diagonal Cracks	Cracks that divide the slab into two or three pieces	Load repetition, curling stress, warping stress, shrinkage stress, and differential expansion of adjacent slabs	Seal cracks, full-depth patch, or slab replacement
Cracks in PCC patches	Cracks form across patch or on patch edges.	Bonding, differential strength and thermal response from adjacent PCC	Seal cracks, replace patch, replace slab (if patch>5 sq.ft.)
Scaling, Map Cracking, and Crazing	Network of shallow, fine, or hairline cracks in the upper surface of the concrete	Generally results from overworking or overfinishing concrete; may also stem from Alkalai-Silica reaction between cement and aggregate	Leave as is (minor), partial-depth or full depth patches, slab replacement
Settlement or Faulting	Difference in height at a joint or crack	Upheaval or consolidation in supporting layers, may result from poor load transfer	Leave as is (minor); grind slab flush, slab replacement
Spalling	Disintegration of slab edges within 2 ft. of a joint or corner; cracks don't extend full depth, but intersect the joint at an angle.	Excessive stresses at the joint from infilling of incompressible material or traffic loads; can result from overworking concrete	Leave as is (minor) or partial-depth patch

As indicated by the multitude of pavement afflictions, the steward of airfield surfaces must consider a wide array of sources to accurately determine the problem and carefully choose the most appropriate of several remedies. For this reason, accurate assessment of the pavement distresses must be effected using a sound and proven method.

3. PAVEMENT ASSESSMENT METHODS

There are numerous techniques used in the aviation industry to evaluate existing pavement condition in order to investigate and prioritize repair and maintenance actions. These techniques can be categorized into five methods:

- Initial – planned resistance to planned loads
- Visual – experienced engineering judgement is used to assess pavement status
- Impact Measurement – quantifies actual deflection response of pavement
- Ground Penetrating Radar – gives an electronic signature of pavement distress
- Electronic Methods – includes other wave analysis techniques

The importance of each is discussed below.

3.1. INITIAL CONDITION

However, a standardized system is used to determine a pavement's relative structural integrity and an aircraft's relative damage potential to that specific pavement. The first measure is known as Pavement Classification Number (PCN), which indicates the pavement's relative ability to carry aircraft loads in terms of a single wheel load for a given pavement life (Malvar, 2000). The single wheel load is derived by selecting a "design" aircraft that is considered most representative of the pavement traffic. In this way, the aircraft loads can be normalized into an effective load that deflects the pavement irrespective of actual contact area with the pavement surface. By incorporating an equivalent single wheel load (ESWL), the relative structural impact of each aircraft, known as Aircraft Classification Number (ACN), can be calculated with respect to the pavement type and strength of the subgrade. Subgrade strength relates to the calculated value of California Bearing Ration (CBR) for flexible pavements and modulus of subgrade reaction *k* for rigid pavements.

A California Transportation Department (CALTRANS) engineer developed the California Bearing Ratio in 1927 as a means to establish soil resistance to imposed loads (Shahin, 1994). A penetration rod is driven into a sample of water-saturated soil for a certain distance. The load (pressure) required to advance the "spike" 0.1 inches into the soil sample is measured, and then another load measurement is taken after another 0.1 inches of penetration. The measured load is compared with the stress required to penetrate 0.1 inches (1,000 lbs/square inch) and 0.2 inches (1,500 lbs/square inch) for crushed limestone, which results in a scale of 0-100. Crushed limestone was selected as the benchmark because of its excellent stiffness, even when fully saturated with water.

Most soils at airfields are not of limestone quality, however. Some typical values of CBR are 5 for silty clays, 13 for sand-clay mixtures and 20 for clean sands (Horonjeff and McKelvey, 1994). Modulus of subgrade reaction, *k*, is a similar concept, but it measures the pressure required to achieve 0.05 inch deflection of a 30-inch diameter steel plate into the subgrade. The subgrade response to this load is therefore treated like a spring-type reaction that responds uniformly under the rigid pavement slab. For instance, *k* values for very poor subgrades are less than 150 lbs/in^3, fair is considered 200-250 lbs/in^3, and very good is 300 $lbs/in^3$and higher (Horonjeff and McKelvey, 1994). Both CBR and *k* are widely understood and used throughout the U.S. and internationally. The Federal Aviation Administration has adopted both indicators in its guidelines for pavement design, construction and repair. The military adopted CBR and k as subgrade characterization tools, as the Army Corps of Engineers rapidly expanded the number of military-use airfields.

Once the subgrade is characterized by specific measures, the ACN is further defined by four levels of subgrade strength: high (A), medium (B), low (C), or ultra-low (D). Therefore, each aircraft will normally have several ACNs: four for flexible pavements and four for rigid pavements. Then the imposed load is compared to the load resistance, PCN. If the ACN is less than the PCN, the pavement structure can handle the load imposed by that specific aircraft. In some cases, airport managers can use this information to specify routing for larger aircraft (which usually have higher ACNs), or even preclude high-ACN aircraft from using the airfield if the damage potential is too great. This system is widely used by the Federal Aviation Administration (FAA), as well as the International Civil Aviation Organization (ICAO) to ensure that the airfield pavements can adequately support various aircraft loads without decreasing the designed pavement life (Horonjeff and McKelvey, Malvar). Pavement life span should be closely monitored, as the expected longevity of pavements should be weighted heavily when planning maintenance and repair actions. In order to track current condition and predict future condition of pavements, regular surveys need to be completed.

3.2. VISUAL METHODS

When a pavement is first installed, the development of PCN is relatively straightforward in the early stages of the pavement's life. However, imposed loads and environmental forces can make accurate PCN determination challenging as the pavement structure ages. As a result, current evaluation techniques, such as the Pavement Condition Index (PCI) and the Structural Condition Index (SCI) are implemented to assess updated pavement performance and to project deterioration rates (Malvar, 2000). A maintenance and repair action plan can be developed from this current and relevant data. The PCI is a numerical method that deducts points for various pavement distresses on a scale of 0-100, with the upper number representing perfect condition. The data is captured by visually inspecting unit areas for the types of distresses described in Tables 2.1 and 2.2 and by evaluating the severity of each type of distress mode. Based on the trends seen in the sampled areas, the frequency, mode, and severity of the noted distresses are extrapolated to find a composite index for each major section of the airfield. The SCI is calculated in a similar way by deducting only points for those distress modes related to directly to structural performance of the pavement. A great deal of experience, training, and sound engineering judgment is required for accurate evaluations of PCI and SCI. Such methods are an excellent starting point in formulating a maintenance and repair plan. However, verification of these analyses is recommended, since the exact nature of each distress is difficult to determine completely. (Malvar and Cline, 2000). Several pavement testing techniques are available to provide a cross-reference.

3.3. PAVEMENT CONDITION TEST METHODS

In order to determine the actual condition of critical airfield pavement sections, two main methods are used: destructive testing and non-destructive testing (NDT). Numerous techniques are currently in use that provide measurable pavement response data for incorporation into pavement repair and rehabilitation designs. In particular, the Falling Weight Deflectometer (FWD), and the Heavy Weight Deflectometer (HWD) have proven especially useful for measuring actual pavement performance under an imposed load (Malvar et al, 1999). A surface deflection basin results from the impulse load, which is typically a gravity accelerated weight. The shape and behavior of the deflection basin shown in Figure 3.3.1 provides insight as to the integrity of the pavement section (WSDOT, 1998).

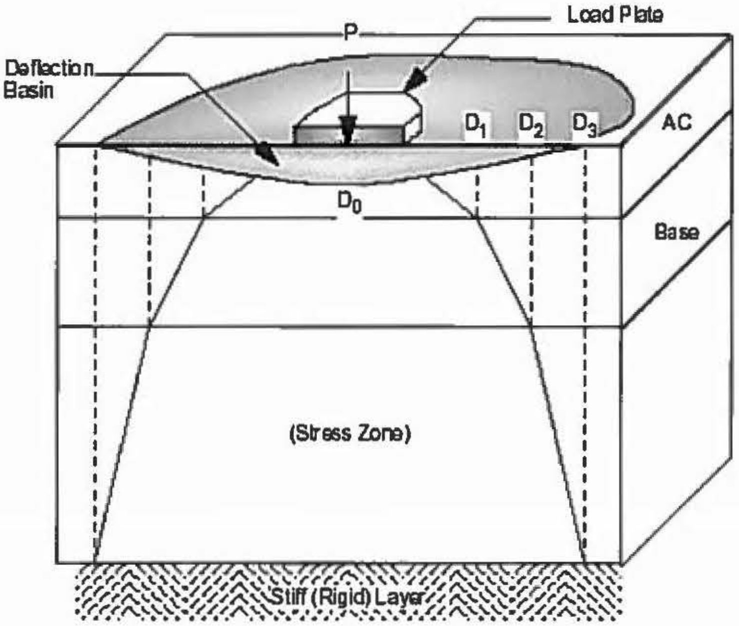


Figure 3.3.1 Example Pavement Deflection Basin

The diagram shows how the depth and radius of the depression relates to the stiffness of the pavement section. The deflection sensors are located along points D1, D2, and D3 to measure how wide and deep the pavement flexes upon impact with a 65,000 lb. force (from an HWD) on the plate, P, shown above. The ability of the pavement to resist this deflection is an accurate representation of its structural integrity.

M. Y. Shahin implicates the utility of these measurements for both asphalt and concrete. For asphalt pavements, FWD/HWD data can determine elastic modulus of each structural layer, pavement structural adequacy, overlay thickness design, load limits, and remaining structural life. Likewise, similar data is gathered from PCC pavements in terms of elastic modulus of concrete and modulus of subgrade reaction *k*, load transfer effectiveness, detection of voids, sufficiency of pavement structure, and even recommended repair strategy.

Several pavement design programs utilize the results of the NDT samples to enhance the accuracy of the proposed remedy for repair and maintenance of pavement sections. In general, most of these software programs are based upon layered elastic analysis for new and overlay section designs. Layered elastic theory takes into account the anticipated pavement loads, the structural support of each pavement layer and the performance of the composite unit, as indicated in FAA Advisory Circulars.(FAA, 1996).

By contrast, destructive testing involves cutting core samples to find actual pavement depth and composition and allowing for subsurface conditions to be sampled. One of the preferred methods to measure subgrade stiffness is the Dynamic Cone Penetrometer (DCP). This measurement measures the soil's ability to resist intrusion by a steel spike. Engineers can use this data to estimate the actual stiffness of the pavement section in the area measured. These techniques are more time consuming and require repairs immediately after completion, so they should be used sparingly (Malvar et al, 2000). More complex analysis tools are capable of integrating most forms of pavement condition measurements. One such method is Finite Element Analysis.

3.3.1. FINITE ELEMENT ANALYSIS FOR PAVEMENT OVERLAY DESIGN

In addition to commonly accepted layered elastic design methods previously mentioned, techniques based on Westergaard's analysis and Winkler foundation can implement finite element analysis (FEA) to yield accurate and effective designs for pavement overlays. FEA stresses the contribution of the subgrade to the overall stiffness of the PCC slab. Ideally, the modulus of subgrade reaction, *k*, is constant throughout the support area by providing consistent "spring-like" responses to imposed loads from the PCC above. This uniform behavior from the subgrade minimizes the stresses and strains felt by the PCC pavement under loaded conditions (Seiler and Jones, 1998).

Traditionally, pavement designers use Westergaards's analysis for interior-slab loads; however, much of the PCC pavement distresses are found at the PCC joints. For this reason, both the interior loads and edge loading conditions are considered in FEA for improved pavement performance (Seiler and Jones, 1998). FEA uses data from HWD samples to back-calculate the pavement's condition and expected remaining life.

3.3.2. GROUND PENETRATING RADAR

Unlike HWD testing, a more innocuous approach to non-destructive testing is the use of electronic and magnetic signature to determine the integrity of pavement sections (i.e. surface, intermediate, base, and sub-base layers). The technology works by applying an electromagnetic pulse wave to the pavement surface and measuring the reflection at one point and refraction at another to draw conclusions about the layer properties. Essentially, any noticeable sharp features or other aberrations in a pavement layer imply the presence of a void or a crack. Ground Penetrating Radar (GPR) is most reliable at higher frequencies (1-2 GHz), which are best suited to capture voids and cracks near the surface of the pavement (<12 inches) (Malvar and Cline, 2000). Lower frequencies on the order of 900 MHz may be used to analyze at lower depths, even below the pavement section. However, the reliability of return signal is greatly affected by the presence of moisture in the pavement layers and subgrade soils. For this reason, GPR is best-suited for dry conditions (Malvar and Cline, 2000). Malvar suggests that the lower frequency waves contain less energy; thus, the reflected and refracted waves are more easily distorted and absorbed on their way back to the surface. An example of some recent GPR results are shown in Figure3.3.2.1 (Malvar et al, 2000).

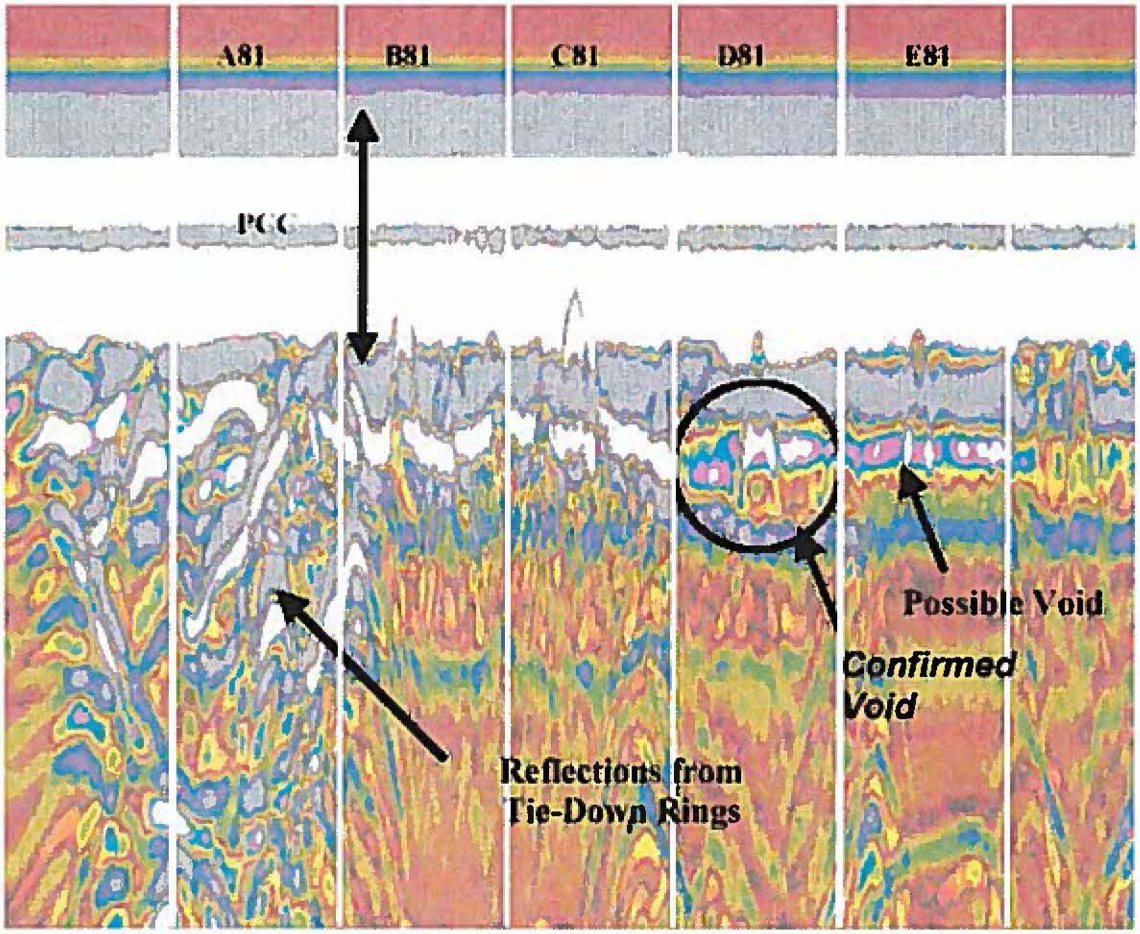


Figure 3.3.2.1: Typical Ground Penetrating Radar Analysis Data

One of the rapidly improving elements of GPR techniques is the data storage and analysis process, which currently requires tedious efforts of personnel to cover runway areas. For this reason, as well as the reliability and ease of GPR data analysis, GPR is primarily used to check for voids and cracks in pavement that overlies drainage pipes and other utilities that cross a runway, taxiway, or parking apron. GPR can also be an effective verification for voids and distresses noted by other techniques, especially Heavy Weight Deflectometer data. Data correlation is generally recommended in order to maximize speed and accuracy of pavement evaluation. One of the other methods used to detect and correlate pavement cracking employs infrared sensors.

3.3.3. INFRARED SURVEYS

Infrared thermography, as the name implies, uses temperature differentials to localize discontinuities on the surface, within, and underneath AC and PCC pavements (Malvar and Cline, 2000). Temperature gradients are evident at periods of extreme heat (mid-day) and extreme cool (several hours following sunset). Any cracks or underlying voids will exhibit a temperature differential from the surrounding pavement and can thus be mapped and further investigated. One advantage of this method is its speed. A vehicle-mounted infrared sensor system can gather this type of data at speeds of approximately 10 mph without accuracy degradation. However, features of pavement voids are vague at best and must be further investigated to determine more specific size and character data. Correlating data can be gathered by previously mentioned methods, or by some newer techniques of detecting pavement distress.

3.3.4. DEVELOPING TECHNIQUES

Airfield managers and engineers should devote some attention to new and innovative techniques in pavement assessment, since several of these new technologies are earning credibility and providing valid evaluations of pavements for alternative and supplemental approaches. Two of the more prevalent methods – seismic and ultrasonic – are discussed below.

Seismic: A few seismic methods of pavement NDT employ technologies adapted from earthquake detection and measurement. Generally, aberrations in the velocities of seismic waves are measured to determine changes in the properties of the examined pavement section. In cases where subsurface problems are suspected, a cross-hole analysis can detect problems in saturated clays. This application, while more accurate than GPR in saturated soils, is rather time consuming, labor intensive, and thus generally less cost-effective (Malvar et al, 1999).

Ultrasonic: Ultrasound can be applied to pavements in a manner similar to ultrasound uses in aircraft frame evaluation and medical purposes. The user can examine the pavement for evidence of cracking in its various layers and de-bonding between layers, as well as localization of voids. However, the depth of the pavement limits the accuracy of the signature, so ultrasound requires further advances in order to accurately analyze pavement structures of greater depth.

Selection of these techniques should include consideration of the types of distress expected, the size of area to be sampled, the feasibility of airfield pavement closures, and the cost to perform each. New developments in seismic and ultrasonic methods include further automation. These new methods may become a better value, as increased automation will likely lower prices and increase accuracy. Exactness of the assessment data is particularly important, as it forms the foundation of the future success of the maintenance options selected and implemented. Gathering reliable data on the pavement's current condition is an important priority, as it is crucial to the next step of the maintenance process: selecting a pavement design.

4. TOOLS FOR DESIGN AND EXECUTION

4.1. PAVEMENT OVERLAY DESIGN CONSIDERATIONS

The accurate assessment and testing of the existing pavement is the lynchpin to ensuring the sustainability of the improved pavements. Of the many inputs needed to upgrade the performance of pavement, proper evaluation of structural integrity is most significant. In addition to structural integrity, the pavement assessment should include surface condition, determination of each layer's depth and structural condition, as well as subgrade soil category (FAA, 1996). Furthermore, non-destructive testing should be accomplished in areas where distresses may indicate the presence of subsurface voids caused by pumping action of excessive ground water. The condition of underlying pavements will influence the decision to either replace the entire pavement section or conduct repairs first, then overlay with an appropriate thickness of ACP or PCC to restore or upgrade the pavement's structural capacity and ride quality. Prior to final selection of overlay design, a life-cycle cost analysis should be conducted in accordance with recommended Pavement Management System (PMS) procedures (FAA, 1988 and US Army, 2001).

Both the Federal Aviation Administration and the Unified Facilities Criteria for Airfield Pavements espouse a "deficiency" method for overlay design. Essentially, the existing pavement is assessed and translated into an effectively thinner pavement layer of similar material. The conditions of the subgrade soil also affect the overlay thickness design. California Bearing Ratio (CBR) is used for ACPs , while modulus of subgrade reaction *k* is used for PCC pavement; both characterize the amount of support that is provided to the base or subbase layers. Both design guides use a series of tables to convert the existing pavement layers into an equivalent thickness of new pavement. The design tables and overlay thickness equations are empirically based and implemented according to the type of substrate and type of overlay to be applied. For example, an existing PCC pavement is evaluated for cracking and reduced in thickness by a pavement condition factor C, which is less than or equal to 1, depending on the severity and frequency of cracking. The in-place modulus of subgrade reaction and concrete flexural strength is applied to other design curves to yield the thickness of an equivalent new concrete pavement section. This new pavement thickness is adjusted by a fatigue scaling factor F, which accounts for the amount of cracking anticipating during the overlay pavement's service life. The thickness of the overlay is determined by multiplying a constant by the difference in thickness between the adjusted "new" PCC and the existing PCC pavement. Below is the FAA's formula for flexible overlay on concrete.

$$t_o = 3.0(Fh_d - Ch_E)$$

Formulas for other pavement overlay configurations are more complex, but like the formula shown above, all are empirically based from US Army Corps of Engineers and FAA airfield pavement histories and experience. In order to avoid mathematical sensitivity to this design approach, both agencies recommended a minimum thickness for each configuration of structural overlay, as shown in Table 3.1 below (US Army, 2001 and FAA, 1996).

Table 4.1: Minimum Recommended Overlay Thickness

Overlay Description	FAA Min. Thickness	Military Min. Thickness
Plain Concrete (unbonded)	5 in.	6 in.
Plain Concrete (fully bonded)	3 in.	2 in.
Reinforced Concrete	---	6 in.
Fibrous Concrete	---	4 in.
Asphalt (light traffic loads)	3 in.	3 in.
Asphalt (heavy traffic loads)	3 in.	4 in.

As indicated in the data above, Department of Defense engineers appear to favor a more conservative approach with thicker pavement requirements, most likely because of the fiscal and operational advantages that military airfields enjoy over their commercial counterparts. Both agencies, however, advise rounding up calculated values of overlay thickness to the nearest ½" for ease of construction.

Occasionally, the condition of existing rigid pavement may be quite poor, but not completely rubblized at the surface. Rather than eliminate an overlay design from consideration, a technique known as cracking and seating of the PCC pavement has been proven effective in the past. Both FAA and military authorities recognize this method, which M.Y. Shahin defines as breaking the PCC into 18-24" pieces with a hydraulic, pneumatic, or gravity pavement breaker. The goal is to create a high-quality base course aggregate by compacting, or seating, these pieces with a pneumatic tire roller for a durable layer that is not inclined toward movement. Cracking and seating will require a noticeably thicker overlay; but, this option may surpass others in the life cycle cost analysis, as the effects of reflective cracking are delayed. Flexible overlays generally exhibit cracking at locations directly above existing joints in the underlying PCC pavement.

One method to combat the onset of reflective cracking is installation of an intermediate layer of coarse-aggregate asphalt concrete prior to the ACP wearing course. The larger aggregates provide better interlock and more even distribution of loads to the underlying PCC pavement. Thus, the strains related to reflective cracking are partially absorbed (FAA, 1996). Another technique appropriate for warmer climates is installation of synthetic, geotextile paving with an asphaltic tack coat directly beneath the asphalt overlay. While a limited amount of the horizontal tensile strain from the base PCC layer can be absorbed by the paving fabric, its primary benefit is the ability to prevent moisture from intruding from the surface to the underlying PCC and vice versa. The moisture barrier properties of asphalt impregnated paving fabric have been shown to retard the development of reflective cracking in ACP overlying PCCP (Holtz et al, 1997 and Shukla, 2002). Airfield engineers and managers should be aware of alternatives such as paving fabric and other new pavement types, including Resin Modified Pavement.

4.2. RESIN MODIFIED PAVEMENT

The engineer has a menu of options when repairing pavements exhibiting a wide spectrum of surface conditions and structural integrity. Several pavement types and installation methods have been developed over the past twenty years. One of the more notable and relatively new pavement types is Resin Modified Pavement (RMP).

RMP can be considered a hybrid between standard PCC and AC pavement. Although standard PCCP is often sealed with fuel-resistant joint sealants, frequent contact with jet fuel and hydraulic fluids degrades the integrity of the sealants, which accelerates the timeline for regular maintenance actions. ACP also suffers from early deterioration from exposure to petroleum-based products and similarly results in accelerated need ACP surface rehabilitation. Aircraft refueling stands and parking aprons are the most vulnerable to early degradation of sealants and wearing courses. RMP was employed in response to the need for better performance on fuel-rich airfield pavements (Anderton, 1998).

RMP is designed as a 1.5 – 2.5 inch wearing course to be applied on top of standard ACP or PCCP. The basic ingredients to RMP are an open-graded ACP and a special portland cement grout with a resin modifier. According to Anderton, the aggregates used in the open-graded mix are generally durable, uniformly graded, crushed rock included to achieve the desired porosity, while maintaining enough contact to achieve good aggregate interlock. In order to allow the grout mixture to adequately infiltrate the open graded ACP, the design targets 25-35% air voids after minimal compaction, versus approximately 7-8% air voids after full compaction in standard wearing course mix designs. The signature characteristic of RMP is the grout mixture, which uses a specialized resin to fill the porous ACP and create a pavement that is stiff, durable, and resistant to chemical breakdown. A slurry grout using standard Type I portland cement, high-quality crushed 75μm sand, enough water for a water-to-cement ratio of 0.65-0.75, Type F fly ash that is not "hydraulic," and a small amount of resin material (usually 2.5-3.5% by weight). This resin material works as a super-plasticizer initially, and then adds stiffness and durability to the grout upon curing (Anderton, 1998).

The construction process for RMP from mixing to load application deviates only slightly from widely used techniques for AC and PCC pavements. The open-graded ACP can be mixed at a standard asphalt plant, hauled to the site in dump trucks for application via conventional paving machines, and then smoothed by only a few passes of a small steel wheeled roller. For this reason, temperature of this ACP mix requires less monitoring than its more common counterparts. The resin modified grout can be produced at standard concrete batch plants by adding the cement, sand, water, and fly ash together in the transit mixer truck. Anderton notes that the sequence for adding the resin mixture to the grout must be made based on travel time from the batch plant to the site of installation. If travel time to the site is less than 20 minutes, the resin mixture can be added to the truck's drum at the batch plant; otherwise, the resin should be added at the site. In transit, the grout must be continuously mixed until arrival at the site, when the resin-modified grout is then mixed at top rotational velocity for approximately 10 minutes to achieve a uniform mixture.

Since workability of the resin slurry grout is too low to be measured by standard slump cone tests, a Marsh flow cone is used to measure viscosity. Viscosity is indicated by the amount of time needed for one liter of grout to pass through the cone. Ideally, this time should be 7-10 seconds, which implies a balanced mixture that will penetrate the voids in the ACP and will mitigate the risk of excessive segregation and shrinkage (Anderton, 1998). The viscosity can be changed at the site by adding slight amounts of water or resin mixture, but the tight quality control up front is preferred.

After a successful viscosity test, the substance is then poured onto the ACP surface directly and leveled by hand via brooms or squeegees. The transit mixer's chute can distribute a swath of grout to achieve saturation of the ACP and then advance forward. Anderton recommends the use of two-by-four timbers to "form" paving lanes and prevent the grout mixture from infiltrating previously grouted areas. A small vibratory roller closely follows the transit mixer to ensure the voids of ACP are filled to the maximum extent practicable and any excess material is pushed forward to achieve the desired pavement roughness. In order to check the shrinkage action and improve the curing process of the modified grout, Anderton suggests a light application of membrane-forming curing compound immediately after leveling. Saw cut or formed construction joints are not required because of the water-reducing characteristics of the resin additive in the grout mixture. However, the long-term performance of RMP without any segmenting has not been conclusive to date.

The labor requirements of RMP are greater than traditional ACP, but less than traditional PCCP. Likewise the costs of RMP installation interpose the two more conventional products. ACP costs approximately $4-7 per square yard, RMP costs approximately $14-21 per square yard, and PCCP is estimated at $25-55 per square yard for 2 inches of thickness (costs adjusted to 2003 by 4% annual inflation) (Anderton, 1998). The value and desirability for RMP is indicated by its limited need for maintenance once installed, its durability against petroleum products, and its lower life cycle costs.

Several factors make RMP an attractive option: 1) RMP's lower maintenance requirements when compared to ACP and PCC; 2) fuel resistance comparable to PCC; 3) lower cost than PCC; 3) relative ease of installation; 4) lower life-cycle costs than both AC and PCC pavements. However, several disadvantages should be noted. First, grout mix designs cost 1.5-1.8 times conventional PCC mixes. Second, resin modified grout is sensitive to proper mix proportions. Third, RMP is not yet widely familiar to construction crews and has greater potential for installation procedural errors that lead to accelerated deterioration. Furthermore, when replacement of RMP is needed, milling or removal will likely be more difficult and costly than conventional AC pavements, as evidenced by the higher prices of PCC grinding versus ACP cold milling prices (Anderton, 1998).

Overall, as a new alternative pavement, RMP is worthy of consideration, especially for use on aircraft hard stands, parking aprons, and refueling stands. Airfield managers should seek these new technologies, since creative solutions are often needed to solve funding-constrained problems. One innovation that can preventively extend the life of PCC pavements is the concrete maturity meter. As a major advance in quality control, maturity meters accurately guide the timing of saw cuts for contraction joints which are installed only a few hours after the concrete is placed.

4.3. MATURITY METERS

Contraction joints are installed in PCC pavements to control shrinkage cracking that occurs in a random pattern during the concrete curing process. Most of the stresses occur within the first 12-96 hours after placement. For this reason, 3/8" – 1/2" wide sawcuts are made approximately ¼ of the depth of the concrete slab to control the cracking pattern. For instance, a 16" thick slab would get a 1/2" wide and 4" deep crack to guide the shrinkage cracks that form during concrete curing. Slabs on airfields are generally cut into squares that are 20 – 25 feet on each side for maximum stress relief while minimizing linear footage of sealed joints.

In the past, determining the optimum time to saw cut the new concrete was difficult to determine, since each batch of concrete is unique and its environmental conditions continuously changing. Thermocouple technology was introduced over 60 years ago that used a basic thermocouple embedded in the green concrete to provide a temperature reading. The relationship between internal concrete temperature and level of curing has been well established for decades (Tikalsky, 2001). Modern maturity meters embed a thermocouple integrated with a small microchip to process and store data. Wires leading to the surface of the concrete can be connected to a maturity meter within the first several hours after placement (as soon as the concrete has gained adequate strength to accommodate foot traffic). Maturity meters are programmed to calculate the compressive or flexural strength of the concrete based on the specific mix design and its corresponding strength vs. time curve. Within the past few years, cell phones have been included in the maturity meter so that certain strengths or temperatures will automatically trigger an alphanumeric pager. Figure 4.3.1 shows the components of a modern concrete maturity meter.

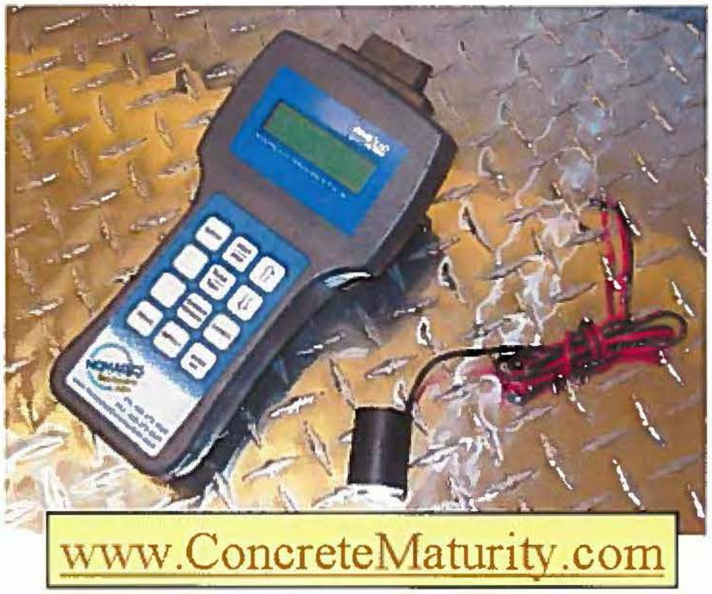


Figure 4.3.1

Upon notification, the saw cutting contractor can immediately mobilize and then cut the joints into the curing concrete at the optimum time. The ideal time to saw cut the contraction joints arrives when the concrete has gained enough strength to handle personnel and saw machines, but still not strong enough for random cracking patterns to develop or cause sawing time to increase because the concrete is stronger. An added advantage of maturity meters is cost-effectiveness, as their precision timing saves labor dollars, crew standby dollars, and the material costs of fewer saw blades consumed during the cutting process.

5. PLANNING AND EXECUTION

5.1. MINIMIZING PROJECT IMPACTS ON AIRFIELD OPERATIONS

In the past, nighttime work in construction was not embraced for two primary reasons: first, labor costs can be significantly higher and second, the safety of the crew and quality of the product requires much greater attention at night. However, the costs incurred by major hub airports during runway outages far outweigh the risks noted earlier. For runway maintenance and repair actions, major hub airports normally specify nighttime work in their contracts between the hours of 10:30 p.m. until 6:00 a.m. A thorough safety plan that addresses additional job site hazards must be developed and enforced. In addition, a robust lighting system will minimize the detrimental effects of poor visibility to quality and safety. In the case of taxiways and aircraft parking aprons, airport operations personnel can often devise aircraft traffic routing plans that add minimal taxi time and allow daytime construction operations on carefully selected taxiway segments and apron slabs.

In order to effect concrete slab repairs on active runways, the entire slab is generally removed in high-traffic areas, such as the runway touchdown zone. Installation of lifting eyes in the existing slab can be quickly executed, so that the slab can be removed and the subgrade prepared in one nighttime work shift. To allow normal air operations to continue by 6 a.m. the next morning, a pre-cast "temporary" slab of equal thickness is installed for that day's traffic. The subsequent nighttime work shift then removes the "temporary" slab (which has steel lifting points already embedded), delivers the high-early strength concrete, places the concrete, saw cuts joints, and installs joint sealant all in the same 7.5 hour work shift (Port of Seattle, 2002). The concrete gains strength so rapidly that aircraft traffic is allowed to travel across the new PCC slab by 6 a.m. the following morning. The vast success of these techniques highlights some of the installation advantages of PCCP over ACP at commercial airfields. The tight timelines for completion of airfield repairs outweighs the greater PCCP costs of construction schedule for airfield repairs projects is so important that it can drive the selection of materials, as noted above. A holistically developed schedule is a crucial requirement to a smooth, effective, and long-lasting pavement upgrade. The success of the project begins in the very early planning phases.

5.2. CONSTRUCTION SCHEDULING CONSIDERATIONS

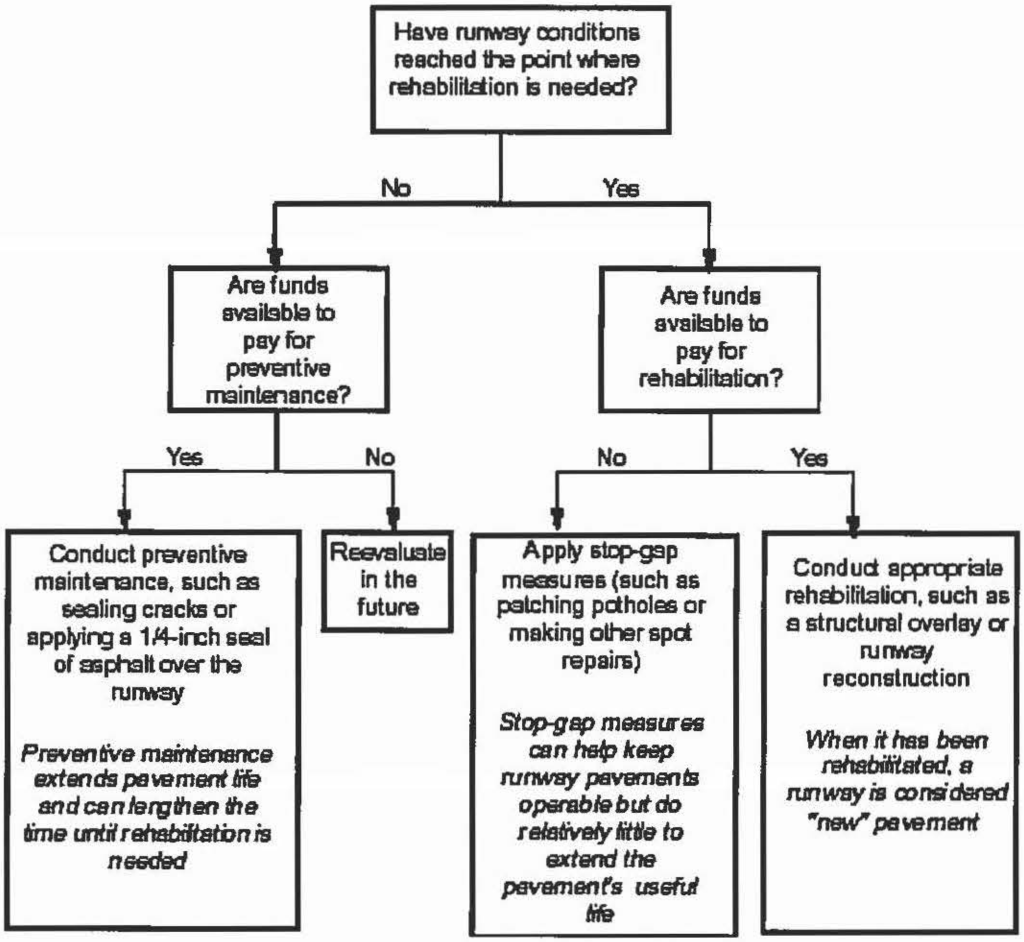
During the concept and design phases of airfield pavement maintenance and repair projects, the project planning team should devote some attention to possible noise issues arising from anticipated construction techniques. Factors that increase construction timelines include: limits on runway and taxiway outage durations, airport safety restrictions, and tough environmental regulations.

One of the most challenging environmental factors is noise mitigation requirements. Community members who live in the vicinity of airfields are often aware of established noise restrictions in their district. For this reason, equipment and process noise should be determined using experience and engineering judgment. Nighttime projects often require comprehensive noise mitigation and abatement plans, including equipment routing considerations and designs for noise barriers. Equipment back-up alarms and pavement demolition processes are two key culprits generating noise complaints (Towers, 2001). Both of these factors add another element of complexity to the already intricate construction sequence. Local regulations may require a plan developed by a certified acoustical engineer to develop methods for controlling and monitoring noise to ensure compliance with established limits.

Towers suggests a few methods for mitigating noise: substituting quieter equipment for noise-generating equipment, modifying construction sequences to minimize coincidence of noisy activities with quiet hours, building barriers in the path of noise transmission, and finally damping noise at the point of reception. All four of these methods increase project cost, require alternative equipment, and often increases the duration of critical path activities, ultimately delaying completion. Time and money are often the top two concerns in a pavement upgrade project, so thoroughness of planning is key.

5.3. CONSIDERATIONS ON PAVEMENT MAINTENANCE AND REPAIR

Several issues must be weighed in developing options and choosing a course of action to improve or maintain airfield pavement condition, including expected life extension of pavement and cost vs. benefit analysis (life cycle costing). Airport master plans should address anticipated aircraft loads and their relative effects on that facility's pavement structures, as well as the planned maintenance and repair actions required to ensure the pavement design life is met. However, many commercial and military airfields are not adequately funded to carry out all planned maintenance at the ideal time and a "critical mass" is sometimes reached. The General Accounting Office (GAO) conducted a study of airfield maintenance at commercial airports in 1998 and the resulting simplified decision model is shown in Figure 5.3.1 below. (GAO, 1998)

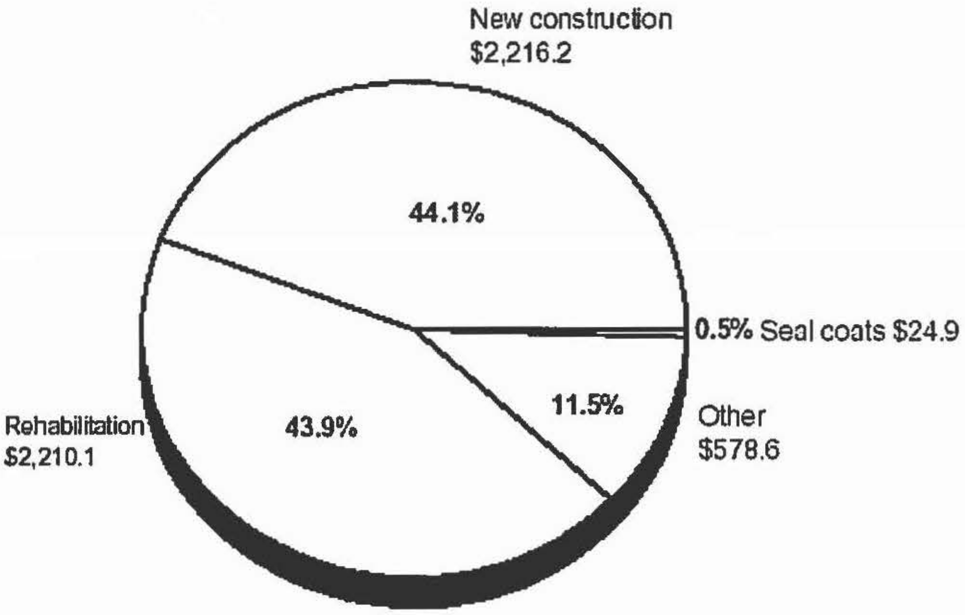

Have runway conditions reached the point where rehabilitation is needed?
No
Yes
Are funds available to pay for preventive maintenance?
Are funds available to pay for rehabilitation?
Yes
No
No
Yes
Conduct preventive maintenance, such as sealing cracks or applying a 1/4-inch seal of asphalt over the runway
Preventive maintenance extends pavement life and can lengthen the time until rehabilitation is needed
Reevaluate in the future
Apply stop-gap measures (such as patching potholes or making other spot repairs)
Stop-gap measures can help keep runway pavements operable but do relatively little to extend the pavement's useful life
Conduct appropriate rehabilitation, such as a structural overlay or runway reconstruction
When it has been rehabilitated, a runway is considered "new" pavement

Note: This figure was developed with the following assumptions in mind: (1) budget considerations are always a factor in determining repair options; (2) pavements do not face some special circumstances that would require repair before they reach the point of needing rehabilitation; and (3) if a lack of funds precludes work from being done, the option to do something in the future will be reevaluated.

Figure 5.3.1: GAO Decision Tree

5.4. PAST HISTORY OF SPENDING AT COMMERCIAL AIRPORTS

The FAA closely tracks and categorizes spending on airfields. The 1998 GAO Report incorporated this data into a graphic that shows how funds were specifically allocated on runway-related projects as shown in Figure 5.4.1. This chart indicates that almost four times more federal funds are allocated towards pavement rehabilitation than pavement maintenance. Furthermore, maintenance of pavements is best achieved during the design and construction phases, in order to extend performance timelines until rehabilitation is needed. Since funds for many or most pavement projects are severely limited, sound judgement and an investment approach should be used when planning and executing pavement rehabilitation. This philosophy gave rise to Pavement Management Systems, which take a holistic approach to the installation, maintenance and repair life cycles of various pavements.



Note: Other projects include grooving, friction treatments, helicopter landing areas, noise compatibility (as a consequence of a runway project), miscellaneous safety areas, and environmental mitigation construction (as a consequence of a runway project).

Source: FAA data.

Figure 5.4.1: Funding Allocation for Airfield Projects

5.5. PAVEMENT MANAGEMENT SYSTEMS

The Federal Aviation Administration has long advocated the implementation of a "big picture" perspective on planning and execution of airfield pavement maintenance and repair. Pavement Management Systems (PMS) are programs designed to capture all costs needed to preserve pavement serviceability and consider the life cycle cost of each proposed maintenance or repair action. Insidious requirements such as recurring pavement condition surveys and joint and crack re-sealing are captured and programmed in the pavement maintenance budget. Routine maintenance actions are incorporated into the life-cycle cost of each pavement repair/upgrade option. In this way, the impacts of short-term repairs can be compared on an equal basis with more extensive projects that often suffer from "sticker shock" because of their up-front cost.

Some of the critical elements of PMS, according to both M.Y. Shahin and FAA Advisory Circular 150-5380-6a, are listed below:

- A system for gathering and storing data on all pavements.
- An impartial and repeatable procedure for evaluating pavement condition.
- A system for developing and comparing maintenance and repair options.
- Methods to predict performance of options and their "whole life" costs.
- Selection criteria and a process that helps determine the best solution.

Development of an effective PMS should be carried out in the order described above because the basis for success relates directly to the accuracy of the pavement mapping system.

Pavement mapping system precision continues to narrow with improved technology. The latest systems couple Geographical Information Systems (GIS) and Global Positioning Systems (GPS) to provide highly accurate mapping of airfield pavement. Once the specific location of each section is defined in a network, the database catalogs the pavement's history of condition, maintenance performed, and configuration. In order to capture the pavement condition, many systems recommend the ASTM procedure for determining pavement condition index (PCI) as described earlier in this document. FAA has developed and refined a PMS called MicroPAVER, which determines the structural condition index (SCI), an approach that is based on the PCI. With this additional information, engineers can make a sound judgment on the feasibility of a thin overlay, a structural overlay, or a complete replacement of a given section of the airfield (FAA, 1988).

PMS deals with specific pavement sections but also considers each option at the network level as well as the branch and section level. A branch is defined as a geographic or functional boundary, such as one specific runway, while a section would further subdivide the branch, such as the touchdown zone of a runway (Shahin, 1994). Thus, separate maintenance actions can be examined at a macro level to determine the priorities that will most improve the pavement network. Table 5.5.1 provides some estimated costs adjusted for inflation to 2003 values for common maintenance and rehabilitation techniques.

Table 5.5.1 Estimated Costs for Pavement Upgrades

Action	Unit	Unit Cost
Joint/crack clean&seal	in ft	2.08
Saw cutting	in ft	5.60
Full-depth ACP patch	sq yd	24.02
Full-depth PCC patching	sq yd	160.10
PCC 8" base course	sq yd	37.64
Tack coat	sq yd	1.01
Aggregate base course	ton	24.02
ACP base course	ton	69.81
ACP wearing course	ton	72.94
ACP milling	sq yd	6.85
Paving fabric w/tack coat	sq yd	4.10
Crack and seat PCC	sq yd	1.20
PCC slab removal	sq yd	56.04

The first line item, joint and crack sealing, should be planned as an annual preventive maintenance action. The cost of each technique should be compared against one another on the basis of durability and longevity. Some of the lower-priced options seem appealing in the near term, but require much iteration.

6. CONCLUSION

Although the charter of airfield managers and engineers closely approaches "Mission: Impossible" proportions, the foundational concepts presented in this paper form a tight locus of waypoints towards long-lasting, healthy pavements. Declining funds and a low tolerance for pavement outages has given rise to complete systems for tracking and measuring pavement performance, as well as designing and executing projects that extend pavement life and improve operational readiness of the airfield.

In order to sustain the performance of pavements, a best-value approach must be engrained in every element of the maintenance program. While cost issues weigh heavily into the programming equation, timing of maintenance actions demonstrates great sensitivity. Figure 6.1 captures this concept concisely: invest in pavement upgrades that will outlast less expensive options many times over, and do it while the pavement is still in relatively good condition.

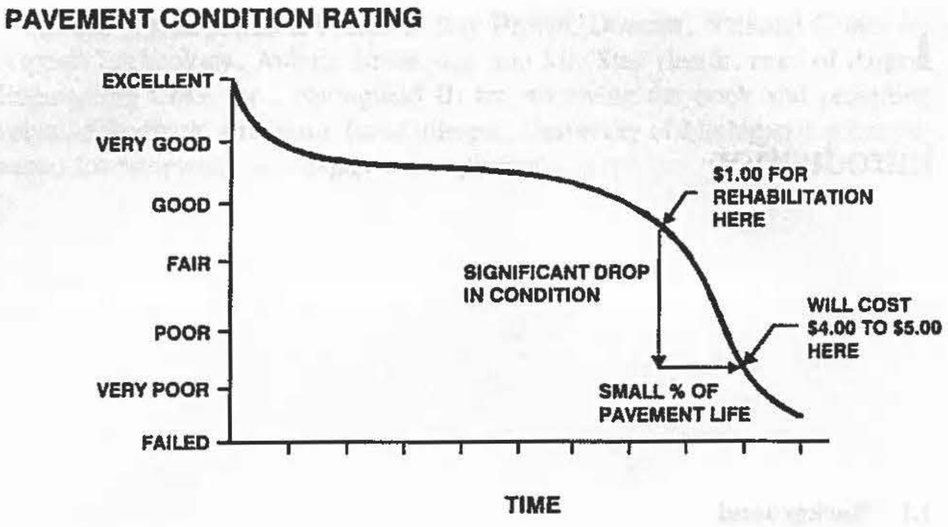


Figure 6.1: Pavement Deterioration Curve

The curve shows a shallow decline in the early phases of a pavement's life, and then a rapid descent into fair, poor, and unserviceable conditions. By determining the signs in the pavement that indicate the breakover point in the condition curve, airfield managers and engineers are able to take proactive maintenance actions, instead of merely responding to emergencies arising from rapid pavement deterioration.

In a sense, airfield stewards can pilot the destiny of their pavements by proactively implementing tried and true assessments such as visual pavement distress surveys and Heavy Weight Deflectometer evaluations. The leaders in the field will complement these proven methods by verifying results with newer techniques. For instance, consider the promising performance of Ground Penetration Radar for detecting pavement cracks and voids. Implement maturity meters to achieve impeccably timed saw cuts in new concrete slabs. Replace petroleum-damaged asphalt pavements with Resin Modified Pavement in fuel-rich areas, such as parking aprons and refueling stands. Maintain your "situational awareness" when planning maintenance projects by carefully considering environmental and safety factors, but not allowing those limitations to drive the project. When pursuing funds for maintenance priorities, utilize Pavement Management Systems that employ life cycle cost estimates that fully capture the recurring expenses of each option. Thus, an "apples-to-apples" comparison of maintenance needs can be conducted to ensure that higher initial outlays don't preclude selection of the best value option. Finally, pavement maintenance is cyclical and demands the constant drive to assess, evaluate, and adjust the pavement management approach and consider utilization of new technologies.

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